IMPROVED PAINTBALL DESIGN AND ALTERNATIVE PAYLOADS

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ABSTRACT

Gelatin paintballs of various shapes and sizes have been prepared to improve the range and accuracy of standard paintball guns for military prison and other military applications. These different marker shapes have been fired successfully, and the effect of shape on range and accuracy is in the process of being determined using computer simulation. Alternative payloads have been incorporated into these more aerodynamic markers and standard paintballs. Commercially available infrared (IR) and ultraviolet (UV) chemicals were used as unobtrusive markers. Anti-traction payloads, including plant oil, propylene glycol, and silicon oil, were found to be qualitatively effective in reducing traction. Obscurant payloads that are opaque pigmented liquids that cure upon exposure to the moisture in air were developed, preventing simple removal of the obscurant. In addition, foaming obscurants are being developed for paintball applications.

1. INTRODUCTION

Alternative payloads have been requested for use in non-lethal projectiles. Unobtrusive markers that are visible outside of the visible spectrum would be useful for identification. Obscurants and anti traction payloads are also desired. Obscurants restrict enemy combatant's field of view while not reducing U.S. forces' field of view. A possible use of this material is to reduce a driver's vision to stop the vehicle, without having to use lethal force. Anti-traction projectiles could be fired on the ground to cause a target to slip and fall. This would increase the ability of subduing a target without using lethal force.

Paintballs are a potential low-cost, low-risk method of emplacing these alternative payloads. Currently, paintball technology is being used to fire heavy duty rounds to deter and mark individuals in riot situations, but the range is limited to ~100 yards (Fazio, 2004) and tagged individuals are not unwitting. The FN303 projectile launcher is used by law enforcement and in some military applications. However, the range of these guns is not sufficient for most military prison applications and special operation missions. Furthermore, the payload and projectile must be completely compatible, to prevent pre-mature rupture and prevent projectile inaccuracies. Lastly, the projectile must be able to successfully deliver enough payload for its given application.

This paper specifically presents work ARL has done to optimize paintball design to maximize range and accuracy. In addition, this work describes the various payloads used and examines their compatibility with gelatin and polystyrene projectiles. Lastly, the functionality of these payloads after being fired by a projectile launcher are qualitatively described.

2. EXPERIMETAL PROCEDURE

Paintball Production

We have developed and hand-prepared three different shapes to improve the range and accuracy of paintball markers: bullet shaped, football shaped, and golf ball surface-textured (Fig. 1). The bullet and football shaped markers have reduced air friction relative to traditional paintballs, which should result in improved accuracy and range. The dimpled golf ball shape results in increased turbulence on the backside of the ball causing improved range (Slonaker and de Angeli, 1997).

Roughly 20 empty gelatin paintballs were cut in half and placed in a vial with 15 mL hot water. The water/gelatin are heated for approximately 15 minutes while stirring occasionally until the solution was homogeneous. To make bullet and football shaped gelatin projectiles, 5 inch long centrifuge tubes were used with a maximum outside diameter of ~0.6 inches. The centrifuge tunes were sprayed with poly(tetrafluoroethylene) mold release so that the gelatin does not permanently stick to the centrifuge tube. The vial was rotated in the warm gelatin, covering the tube halfway (2.5 in). The gelatin was allowed to drip off the tip back into the container until it slowed to a slow drip. The gelatin on the tube was then quenched in liquid nitrogen for about 3 seconds. These last few steps were repeated 3-4 times to give a noticeable film (roughly 3mm) on the vial. The vials were stood upright and let air dry overnight.

The next day, a plumber's copper tube cutter was used to make a straight cut near the bottom of the cured film. The bullet shaped gelatin was removed from the centrifuge tube. The end was then sealed by dipping the open end of the bullet shape in the hot gelatin to allow a

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film to form. The object was rotated to allow for even distribution. Once the film cooled to room temperature, the end was dipped in the liquid nitrogen, and then allowed to cure overnight at room temperature. This produced the bullet-shaped projectile (Fig. 1).

Football shapes (Fig. 1) were created by overlapping the ends of two bullet shaped capsules. Hot gelatin was then used to seal along the joint line. Both the football and bullet shapes could be made with one or more compartments, so that reactive substances could be stored separately (Martinez, 2003). Similarly, spherical paintballs were cut in half and capped into hemispheres using gelatin as previously described for the bullet shapes. Two hemispherical shapes were then immediately joined before the gelatin cooled to bind the spherical shape together. Thus, spherical projectiles were also made with two compartments (Fig 1).

The payload was injected into the projectile using a syringe. The hole created by the syringe was sealed using either a two-part epoxy or gelatin. In either case, the projectile was immobilized and a small drop of the adhesive was placed on the hole. The adhesive was allowed to cure for at least a few hours before using the projectile.

Alternative Payloads

There are a number of off-the-shelf chemicals, inks, and solutions that are visible only in the infrared (IR) or ultraviolet (UV) spectra. Certain inorganic and inorganic/organic lanthanide compounds are excited in the UV, visible, or near infrared and produce emissions in the infrared spectrum (Geiser et al., 2003). Quantum dots are nano-scale semiconductors that absorb and fluoresce at defined wavelengths depending on the size and composition of the quantum dots (Bruchez et al., 1998). Cadmium selenide and lead selenide nanoparticles of 2-9 nm are the most common quantum dots manufactured and used. Chemiluminescence is the generation of electromagnetic radiation by the release of energy from a chemical reaction (DeLuca, 1978).

Proprietary IR dyes from LDP, IR phosphors from LDP, and IR quantum dots from American Dye Source produce emissions in the near IR when interrogated/irradiated using specific visible wavelengths. Another IR phosphor from LDP produces up-conversion fluorescence and emits a in the visible spectrum when interrogated in the near IR. UV glow powders and UV invisible inks from LDP are visible to the eye when interrogated/irradiated with a UV source. Other chemical markers used were the two-part chemicals used in Cyalume Technologies chemiluminescent IR and visible glow sticks.

Fig. 1: Various paintball shapes made from traditional paintball gelatin.

IR light sources for marker interrogation include IR flashlights operating at wavelengths greater than 700 nm and IR lasers operating at 1080 nm (Fig. 2). Visible light sources included red laser pointers, and a simple UV lamp for chromatography applications was used as the UV light source. Optical cameras and near IR cameras were used to detect the marker during radiative interrogation. A Canon Power Shot digital camera was used for capturing visible photographs of markers. A Canon EOS Rebel modified with an X-Nite filter that blocks wavelengths below 750 nm was used to capture photographs in the near IR spectrum. All of these markers and equipment are readily available and inexpensive.

Three anti-traction payloads were examined: canola oil, silicon oil, and propylene glycol. Canola oil is a plant oil, and as such, is biodegradable and environmentally friendly. Silicon oil is a synthetic oil. Both oils are not soluble in water and have low surface energy, resulting in their slippery feel. Propylene glycol is water soluble, but is currently the base chemical used in FN303 projectiles.

Fig. 2: Interrogation and detection equipment is simple and readily available and includes (a) night vision goggles, (b) near IR cameras, (c) IR flashlights, and (d) flashlights/laser pointers.

A number of obscurant chemicals were examined. MIL-C-53039, a one component military paint, was used. This paint is not water soluble and reacts with moisture in air to form a cured paint film. Black pigments were mixed with Gorilla Glue™ and cyanoacrylates (super/crazy glue). The cyanoacrylates and Gorilla Glue™ cure upon exposure to the moisture in air to form an obscurant film that cannot be easily removed. In addition, a rapidly expanding foam consisting of two parts was used. Sodium bicarbonate was dissolved in water isopropanol in one component, and acetic acid was used as the second component. Both components used black pigment as an obscurant. Upon breaking of the projectile, the sodium bicarbonate and acetic acid react to form a rapidly expanding foam. Similarly, a mixture of water, sodium bicarbonate, and pigment as one component and Gorilla Glue™, acetic acid, and pigment as the second component should foam and produce a cured film obscurant.

Payload Compatibility with Projectile

FN303 projectiles are made out of polystyrene. Typical paintball markers are made out of gelatin, like the bullet, football, and spherical paintballs described above. The compatibility of the alternative payloads to both gelatin and polystyrene (PS) is therefore important. This was tested by placing a small piece of gelatin or polystyrene into a vial and then filling the vial with various solvents or chemicals. If the gelatin/PS dissolves or breaks apart, then the payload is not compatible. Chemicals that passed this test were then injected into a paintball to more rigorously determine compatibility.

Additives in Chemical Agent Resistant Coatings

IR phosphor chemicals were added to off-the-shelf chemical agent resistant coatings (CARC). Specifically, MIL-DTL-64159 provided by Sherwin Williams was used. The paint with and without IR phosphor additive was spray-coated onto steel panels and tin-coated Q-panels for evaluation.

3. RESULTS AND DISCUSSION

Paintball Production Results

Roughly 90% of the bullet-shaped and football-shaped rounds were fired successfully without jamming inside the gun. This number was relatively low due to their inexact dimensional nature through hand-preparation rather than mass machine production and size-sorting quality control of commercial paintballs. All spherical bullets fired successfully from the gun. Quantification of extended range and accuracy will be measured first using computer simulation. Afterwards, the various experimental ranges at Aberdeen Proving Ground will be used to validate the simulations.

Table 1: Compatibility of gelatin and PS with various solvents. Chemicals highlighted in yellow are compatible with both PS and gelatin.

Chemical	**Solubility in:**	
	Gelatin	**PS**
Acetic Acid	Soluble	Not soluble
Acetone	Not soluble	Soluble
CA-40	Not soluble	Very soluble
Canola Oil	Not soluble	Not soluble
Chloroform	Not soluble	Soluble
Ethanol	Not soluble	Not soluble
Glycerol	Slightly soluble	Not soluble
Isopropanol	Not soluble	Not soluble
Methanol	Not soluble	Not soluble
MIL-C-53039	Not soluble	Not Soluble
Propylene Glycol	Slightly soluble	Not soluble
Silicon Oil	Not soluble	Not soluble
Tetrahydrofuran	Not soluble	Very Soluble
Toluene	Not soluble	Very Soluble
Cold Water	Soluble	Not soluble
Hot Water	Very Soluble	Not soluble
Acidic Water	Very Soluble	Not soluble
Basic Water	Very Soluble	Not soluble

Payload Compatibility with Projectile

Aqueous payloads cannot be used with gelatin paintballs because water dissolves gelatin (Table 1). Hot water, acidic, and basic water dissolve gelatin at a very fast rate. Glycerol did not appear to dissolve the gelatin in the vial. Yet, glycerol caused the paintball to deform noticeably, and was thus incompatible with the gelatin. In general, organic solvents are compatible with the gelatin. Alcohols, such as isopropanol, acetone, THF, toluene, and chloroform did not dissolve the gelatin, nor did the military paint MIL-C-53039. Water, alcohols, and the military paint did not dissolve the PS. However,

THF, acetone, toluene, and chloroform are incompatible with PS, as they readily dissolved it. Plant oils and silicon oil are completely compatible with both PS and gelatin. Overall, simple alcohols, oils, and the MIL-C-53039 paint were usable for both PS and gelatin projectiles.

Marker Characteristics

The splatter patterns for all payloads were approximately 13 cm in diameter (Fig. 3). This was similar to the splatter patterns of commercial paintball markers. Viscosity had little effect on the size of the splatter pattern, but low viscosity markers would run/drip from vertical surfaces at a much higher rate that typical paintball markers.

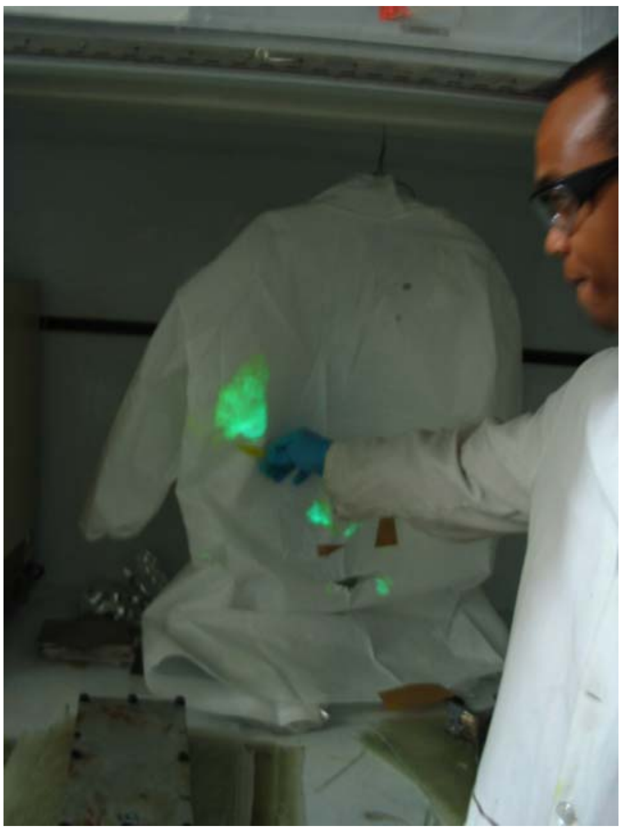

Fig. 3: Visible chemiluminescence (the green glow) showing the splatter pattern and the excellent mixing of the chemiluminescent components.

Dual compartment projectiles were made to allow the use of two component chemiluminescent markers. The two components did not mix when contained in the paintball, but efficiently mixed when the marker hit its target to create a large glowing splatter mark. Visible chemiluminescent chemicals showed that mixing occurred immediately and completely as the chemiluminescent glow was visible immediately after firing the paintball at a surface (Fig. 3).

Markers

The IR dyes from LDP were clearly visible in the near infrared spectrum, but are not detectable in the visible spectrum, as shown in Fig. 4. These IR dyes require no interrogation, as ambient light is enough for these inks to be visible in the near IR spectrum. IR/UV marker chemicals were also successfully applied to clothing (Fig. 5). Dilute solutions of IR/UV chemicals were prepared that are nearly invisible to the eye when applied. However, the mark was clearly observed in either the visible or near IR spectrum when interrogated with the proper radiation.

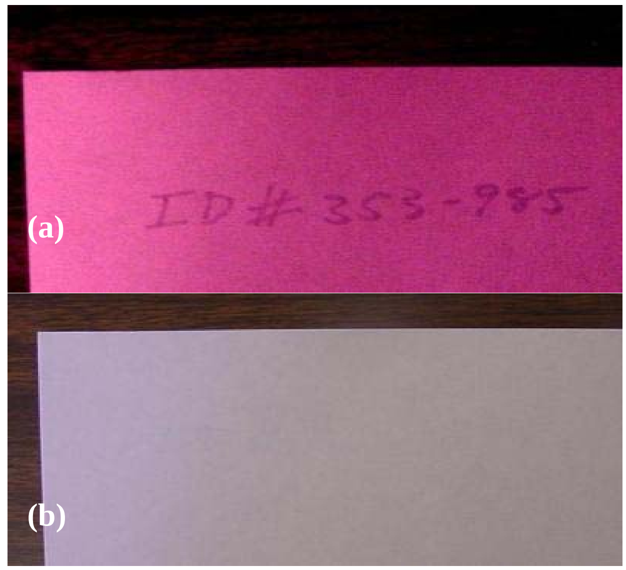

Fig. 4: The IR dye in (a) is clearly visible in the near IR spectrum, but non-visible in the visible spectrum.

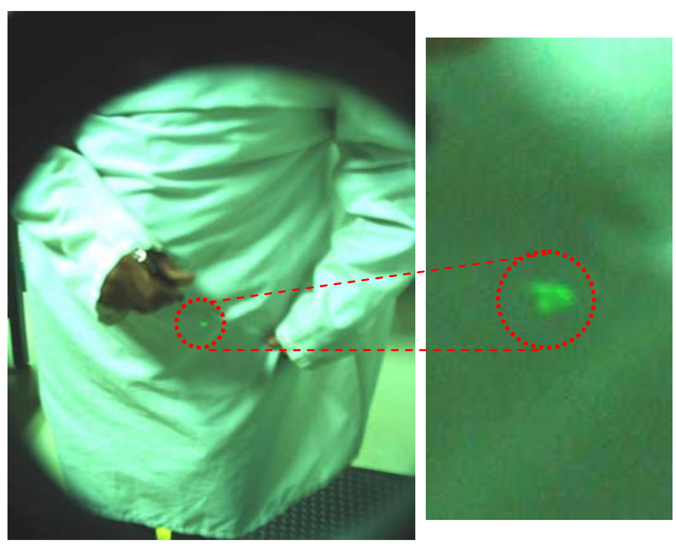

Fig. 5: Marker inside red circle produces a green glow when irradiated by an IR laser.

The IR chemiluminescent chemicals produced a highly visible IR glow that was visible using the near infrared camera, but not in the visible spectrum (Fig. 6).

Chemiluminescent markers require no interrogation, but unfortunately will only serve as a marker for a limited time, as the reaction that provides the chemiluminescence is not unlimited.

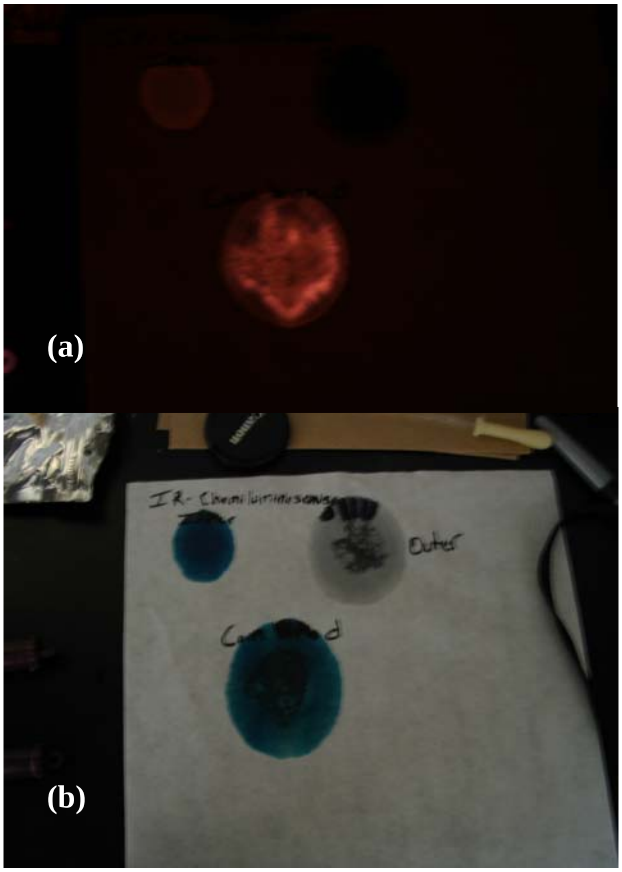

Fig. 6: (a) The chemiluminescent glow as visible in the near IR camera is not visible in the (b) visible spectrum.

The UV dyes and powders have faint color in the visible spectrum, but do not stand out (Fig. 7). Yet, once these chemicals are exposed to UV radiation from the chromatography lamp, the inks and powders glow brightly in the visible spectrum. In fact, after the UV radiation source was removed, and the powders and inks still glowed for a few minutes. This is due to the relatives slow emission process associated with fluorescence (Geiser et al., 2003).

Quantum dot markers were not successfully viewed in the near IR. Quantum dots have low environmental stability, and thus could have degraded, thereby reducing the detection signal below the level of detection. Future work will focus on quantifying the detection limits of these markers.

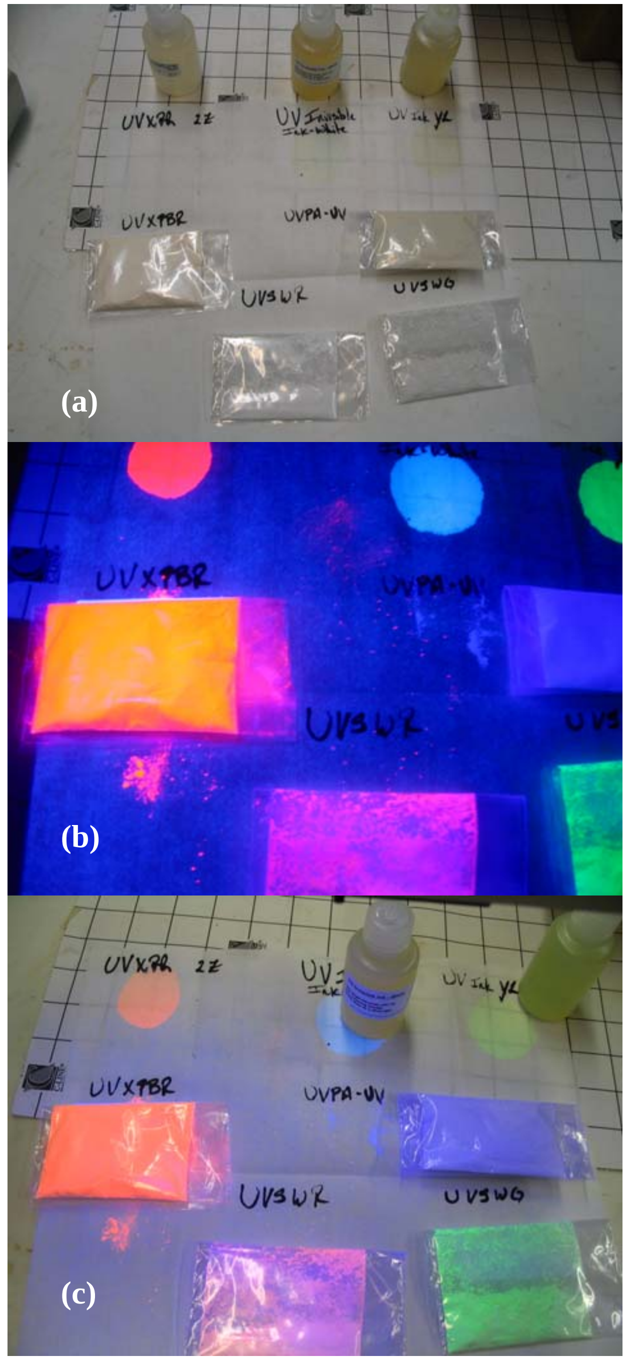

Fig. 7: UV dyes and powders remain unobtrusive in (a) the visible spectrum until (b) they are irradiated with a UV source. At which point, (c) they remain visible up to a few minutes without further UV irradiation.

Anti-Traction Payloads

Paintballs filled with canola oil, silicon oil, and propylene glycol were fired at the epoxy floor in the laboratory. As per the marker payloads, the splatter patterns had an average diameter of ~13 cm. A single shot of these paintballs produced a very slick surface. Multiple shots increased the area of effect. It is expected that other plant oils, such as soybean oil and corn oil,

would exhibit similar properties. As expected, water did not remove the silicon oil or canola oil, and in fact further decreased traction. Organic solvents were necessary to remove these oils. Water was used successfully to clean up the propylene glycol.

Obscurant Payloads

Carbon black was dispersed fairly well into vegetable oil. However, the carbon black settles out of solution within a few minutes, thus limiting this formulation's use as an obscurant. In addition, non-curing paints can by physically removed and are no better than current paintballs in terms of obscuring. On the other hand, formulations with gorilla glue™ hardened rapidly when placed on a surface due to reaction with water and maintained their pigment to obscure vision. Sodium bicarbonate and acetic acid systems foamed readily to increase obscurant area. However, better formulations need to be prepared to prevent settling out of the pigment. The MIL-C-53039 paint is pre-formulated to contain pigments to prevent transmission of light. The paint works well as an obscurant, and it takes a few hours for the pigments to noticeably settle out of suspension. However, as formulated, the paint cures slowly. The use of a water solution in a second compartment enabled this paint to cure very quickly.

Additives in CARC

IR and UV visible chemicals were mixed into the polyol component of MIL-DTL-64159 at less than 1 wt%. The IR phosphors and UV glow powders were not soluble in the polyol component, but were well dispersed through standard paint mixing methods. The IR and UV invisible inks were soluble in the paint component. The polyol component was then mixed with the isocyanate component and water as directed by the manufacturer. The paint was then sprayed 50-75 μm thick onto MIL-P-53022 primed panels. When properly interrogated, panels with the IR/UV chemical were plainly visible compared to regular panels (Figure 8). In fact, concentrations as low as 0.1 wt% were visible. However, there is no visible difference between the two panels as shown by their identical visible spectra.

4. CONCLUSIONS

Gelatin paintballs of various shapes and sizes have been prepared. These different marker shapes have been fired successfully and offer the potential for improved range and accuracy. Alternative payloads have been incorporated into these and standard paintballs. These alternative payloads include IR and UV visible markers, anti-traction payloads, and obscurants. In addition, these markers have been added into CARC formulations to produce panels that look like standard CARC panels, but are visible using specific detection equipment.

Fig. 8: Sample with phosphor is clearly visible after being excited by IR light (left), while plain CARC shows nothing (right).

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